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Microstructure and Creep Properties of TiAl-Ti_3Al In-Situ Composites

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Objectives

- Exploit thermomechanical-processing techniques to fabricate $TiAl/Ti_3Al$ in-situ laminate composites with the size of lamella width down to submicron or nanometer length-scales.
- Characterize microstructure and elevated-temperature creep resistance of the in-situ composites.
- Investigate the fundamental interrelationships among microstructures, alloying additions, and mechanical properties of the in-situ composites so as to achieve the desired properties of the in-situ composites for high-temperature structural applications.

Approach

- In-situ composites with nominal compositions of Ti-47Al-2Cr-2Nb and Ti-47Al-2Cr-1Nb-0.8Ta-0.2W-0.15B (at.%) were chosen for the study. The in-situ laminate composites were fabricated at Oak Ridge National Laboratory by a thermomechanical process, which involves a hot-extrusion (16:1 ratio) of gas-atomized titanium aluminide powder (particle size: - 200 mesh) canned in molybdenum billets and were subsequently hot-extruded at 1400 ° C.
- Creep tests were conducted in a dead-load creep machine with a lever arm ratio of 16:1. Tests were performed in air in a split furnace with three zones at 760 ° C and 815 ° C.
- The microstructures of creep-deformed samples were examined using a JEOL-200CX transmission electron microscope.
- In-situ TEM observation of the motion of interfacial dislocations was conducted by electron-beam heating of a creep-deformed sample.

Accomplishments

- Collaborated with ORNL (Dr. C.T. Liu) to fabricate in-situ $TiAl/Ti_3Al$ laminate composites using hot-extrusion processing techniques.
- Conducted in-situ TEM experiment to record a direct observation of interface sliding within the in-situ composites.
- Characterized and measured the effect of alloying modification on creep resistance of the $TiAl/Ti_3Al$ in-situ composites.

Future Direction

- Continue to collaborate with ORNL to fabricate the oxidation- and heat-resistant class of TiAl/Ti_3Al in-situ laminate composites with higher Nb and W additions using hot-extrusion techniques.
- Continue to investigate the alloying effect on the microstructural stability and creep properties of the in-situ composites at elevated temperatures up to 850 °C.

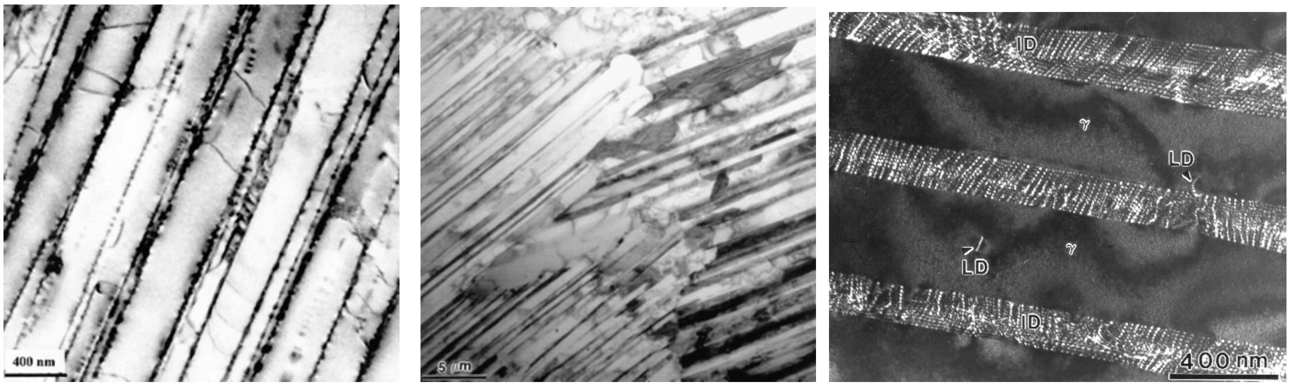
INTRODUCTION

Two-phase [TiAl (γ-L1_0) and Ti_3Al (α_2-DO19)] fully lamellar alloys (or in-situ laminate composites) have recently attracted a great attention because of their low density (ρ = 3.9 g/cc), high specific strength, adequate oxidation resistance, and good combination of ambient-temperature and elevated-temperature mechanical properties, which are of interest for aerospace and transportation applications such as high-temperature components in turbine and combustion engines. Through alloy design and microstructural optimization, significant progress has been made to improve both room-temperature ductility/toughness and high-temperature creep resistance of the in-situ composites [1-6]. A recent report of the formation of nanoscale lamellae (with lamellar spacing in the order of 5 to 10 nm) within a water-quenched TiAl alloy [7] revealed the feasibility of materializing the idea of fabricating TiAl nanophase composites. However, in parallel to make an effort for developing TiAl nanophase composites, there is a need to understand if further refinement of the lamellar microstructures would lead to adverse effects on high-temperature creep properties. A previous investigation [8] on the creep behavior of a Ti-47Al-2Cr-2Nb (at.%) alloy with a refined lamellar microstructure revealed that there existed two distinct creep regimes, where a nearly linear creep behavior was observed in low-stress (***LS***) regime (i.e. σ < 300 MPa at 760°C), and power-law break down was observed in high-stress (***HS***) regime (i.e. σ > 300 MPa at 760°C). TEM investigation of deformation substructures within creep-deformed specimens has revealed the occurrence of interface sliding in ***LS*** regime and deformation twinning in ***HS*** regime, which has led us to propose that interface sliding associated with viscous glide of pre-existing interfacial dislocations is the predominant creep mechanism in ***LS*** regime, and interface-activated deformation twinning in γ lamellae is the predominant creep mechanism in ***HS*** regime [8, 9]. Furthermore, we also suggested that the solute atoms segregated at lamellar interfaces could act as short-range barriers to drag the motion of interfacial dislocation arrays during interface sliding. Accordingly, the main purpose of current investigation was to study the effect of alloying modification on the creep resistance of the in-situ laminate composites. Emphasis was placed upon the solute effect on the creep resistance in ***LS*** regime in order to facilitate the effort of developing TiAl/Ti_3Al nanolaminate composites for high-temperature structural applications.

RESULT

Microstructures of as-extruded materials

Typical lamellar microstructures of Ti-47Al-2Cr-2Nb and TiAl-47Al-2Cr-1Nb-0.8Ta-0.2W-0.15B in-situ composites are shown in Figs. 1 (a) and (b), respectively. Similar colony grain sizes (< 100 μm) and lamella widths were observed within the in-situ composites. The width of γ lamellae varies between 100 nm and 350 nm, and the width of α_2 lamellae varies between 10 nm and 50 nm. These values are considerably finer than those in lamellar TiAl alloys fabricated by conventional processing techniques. In addition, as shown in Fig. 1 (c), interwoven-type colony boundaries were developed within these two lamellar alloys, which could effectively interlock the colony boundaries from rotation and sliding when deformed at elevated temperatures.



(a) (b) (c)

Fig. 1. (a) A bright-field TEM image showing a typical lamellar microstructure observed from Ti-47Al-2Cr-1Nb-0.8Ta-0.2W-0.15B extruded at 1400 ° C; (b) A bright-field TEM image showing a interwoven colony boundary in Ti-47Al-2Cr-1Nb-0.8Ta-0.2W-0.15B in-situ composite; (c) A tilt view of lamellar microstructure showing a dislocation substructure within the in-situ composite (***LD*** denotes lattice dislocation, and ***ID*** denotes interfacial dislocation).

Creep data and deformation substructures

Creep data generated from Ti-47Al-2Cr-2Nb and T-47Al-2Cr-1Nb-0.2W-0.15B in-situ composites tested at 760 and 815 ° C are shown in Fig. 2. As can be seen clearly both primary and steady state creep rates significantly decrease as a result of the solute additions, and W solute is anticipated to be more effective than Ta solute for reducing the creep rates. A nearly linear creep behavior ($n \sim 1.5$) was observed in both Ti-47Al-2Cr-2Nb and Ti-47Al-2Cr-1Nb-0.8W-0.2W-0.15B composites creep-deformed at elevated temperatures with stresses below 300 MPa (i.e. ***LS*** regime). Figure 3 (a) shows a typical observation of a viscous glide (zigzag motion) of interfacial dislocations observed from the specimen deformed at 138MPa, 760 ° C. The zigzag motion of interfacial dislocations is presumably resulted from the locking-unlocking of dislocation lines from solute atoms, which indicates that since the activities of glide and climb of lattice dislocations become very limited as a result of a refined lamellar microstructure, creep resistance of refined lamellar TiAl in ***LS*** regime is mainly controlled by the mobility of interfacial dislocations. The creep resistance of refined lamellar TiAl in ***LS*** regime may be promoted by reducing the mobility of interfacial dislocations by the segregation of low-diffusivity solutes such as Ta and W to impede the motion of interfacial dislocations. Although more rigorous investigations are needed for the effects of solute segregation at lamellar interfaces to the creep resistance of lamellar TiAl in ***LS*** regime, a preliminary result obtained from Ti-47Al-2Cr-1Nb-0.8Ta-0.2W-0.15B sample creep-deformed at 70 MPa, which demonstrates the promotion of creep resistance by the addition of Ta and W is shown in Fig. 3(b). Here precipitates, presumably TiB_2-type boride particles, were observed at α_2/γ interfaces. It is noted that the formation of TiB_2-type particles in similar TiAl alloys doped with boron has been previously reported elsewhere [11-13].

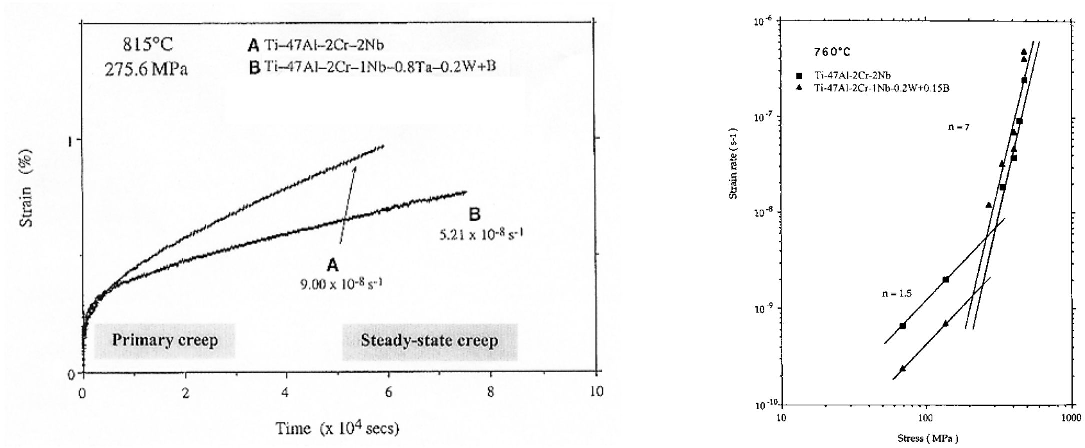


Fig. 2. Creep data show the effects of W, Ta and B additions to the creep resistance of the in-situ composites at 815 °C. It reveals that W solute is more effective than Ta solute for reducing both primary and steady creep rates.

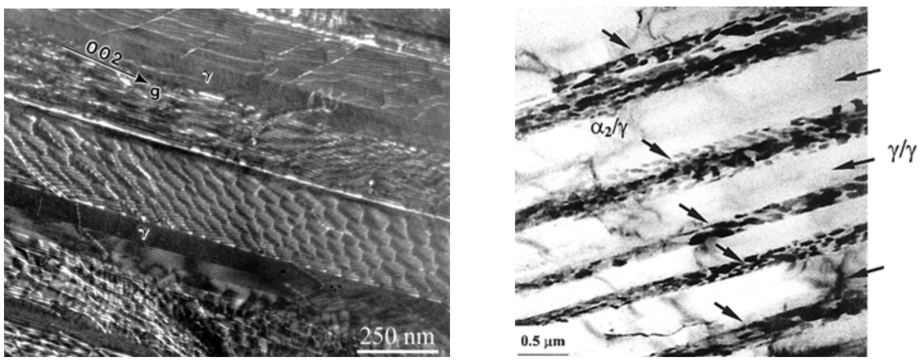


Fig. 3. (a) A TEM image showing the zigzag motion of interfacial dislocation array observed within a sample creep-deformed at *LS* regime (760 °C, 136 MPa); (b) Bright-field TEM images showing the formation of TiB_2-type boride particles at α_2/γ interfaces within a Ti-47Al-2Cr-1Nb-0.8Ta-0.2W-0.15B sample creep-deformed at 760 °C, 70 MPa.

In-situ TEM observation

The results of in-situ TEM observation made from a creep-deformed sample (138MPa, 760 ° C) are presented in Fig. 4 to demonstrate the motion of interfacial dislocations under an electron-beam heating condition. It is noted that a local heating of TEM sample can be achieved by spotting the focused electron-beam (several micron meters in size) onto the region of interest in the sample. Here, two consecutive in-situ images demonstrate the cooperative motion of a dislocation array (total eight interfacial dislocations in the array) in a γ/γ interface during beam heating, and the array moved about 250 nm after beam heating for 20 seconds. The dislocation array stopped moving after re-spreading the beam onto a wide region of the TEM sample. This observation further supports that the creep resistance of TiAl/Ti_3A in-situ laminate composite in ***LS*** regime can be promoted by reducing the mobility of interfacial dislocations by the segregation of low-diffusivity solutes such as Ta and W to impede the motion of interfacial dislocations.

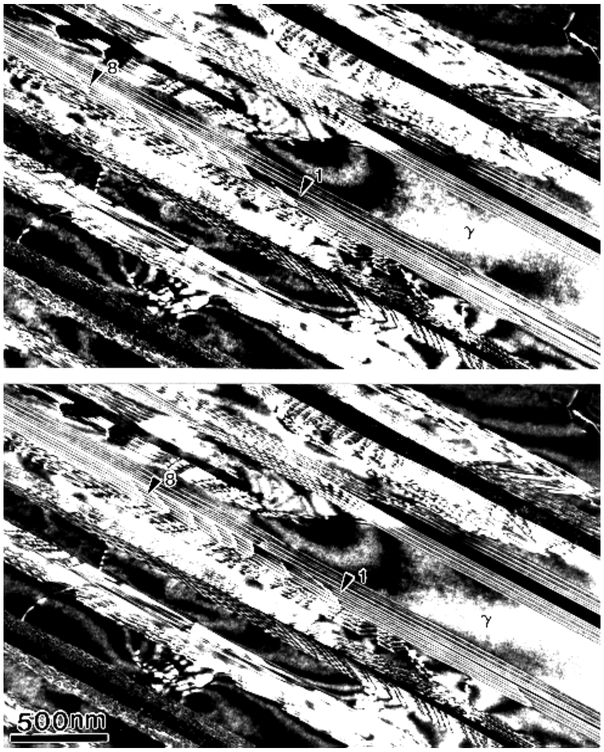


Fig. 4. Consecutive in-situ TEM images showing the motion of an interfacial dislocation array in a γ/γ interface (the time period for beam heating: 20 s).

CONCLUSION

A nearly linear creep behavior [i.e. $\dot{\varepsilon} = k\sigma^n$, $n \sim 1.5$] has been observed in both Ti-47Al-2Cr-2Nb and Ti-47Al-2Cr-1Nb-0.8W-0.2W-0.15B in-situ composites with an ultrafine lamellar microstructure (γ lamellae: 100 – 300 nm thick, α_2 lamellae: 10 – 50 nm thick) creep-deformed at elevated temperatures with stresses below 300 MPa. The resulted deformation substructure and in-situ TEM observation reveal that interface sliding through the motion of pre-existing interfacial dislocations is the predominant deformation mechanism in low-stress creep regime. Since the operation and multiplication of lattice dislocations within both γ and α_2 lamellae are very limited at a low stress level as a result of the refined lamellar spacing, creep mechanisms based upon glide and/or climb of lattice dislocations become insignificant, instead the mobility of interfacial dislocation arrays on γ/α_2 and γ/γ interfaces becomes predominant. It has been demonstrated that solute segregation at lamellar interfaces and interfacial precipitation caused by the segregation have a beneficial effect on the creep resistance of ultrafine lamellar TiAl in low-stress creep regime.

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FY 2003 Publications/Presentations

1. L.M. Hsiung, "Interface Control of Creep Deformation in Ultrafine Lamellar TiAl," Mater. Res. Soc. Symp. Proc. (Materials Research Society), **740** (2003), p. 287.
2. L. M. Hsiung and T. G. Nieh, "Microstructures and Properties of Powder Metallurgy TiAl Alloys," accepted to publish in Materials Science and Engineering A, in press.
3. L.M. Hsiung, A. J. Schwartz, and T.G. Nieh "In-Situ TEM Observations of Interface Sliding and Migration in a Refined Lamellar TiAl Alloy," presented in International Symposium on Intermetallic and Advanced Metallic Materials – A Symposium Dedicated to Dr. C. T. Liu, TMS Annual Meeting San Diego, CA, March 3, 2003; Accepted to publish in *Intermetallics*, in press.